A Robust, Composite Packaging Approach for a High Voltage 6.5kV IGBT and Series Diode

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Introduction – Current Switch

WHAT ARE THE PROS AND CONS
WHAT IS THE PURPOSE OF SHOWING THESE
WHAT DOES A MECHANICAL ENGINEER NEED TO KNOW ABOUT THESE

- Series connected transistor and diode make up the basic switching unit of power converter
- Provides bidirectional blocking, and unidirectional current characteristic
- Design application is for a solid-state transformer for the Smart Grid

IGBT & Diode
MOSFET & Diode
Reverse Blocking IGBT
Introduction – Current Switch-based Topologies

DO YOU EXPECT PEOPLE IN THE LAST ROW TO SEE THIS?

- **Advantages:**
  - Matured technology
  - Uses conventional controller
- **Disadvantages:**
  - 3 Stages = greater number of devices
  - Hard switched
  - Bulky capacitors

DO PEOPLE KNOW WHAT “SOFT SWITCHED” MEANS?

- **Advantages:**
  - Low number of devices
  - Soft switched
  - High \( f_{SW} \) = smaller passive components
- **Disadvantages:**
  - Complex controller

Effect of Packaging Parasitics on Series Current Switch

Test circuit with series parasitic inductance

Test circuit with parallel parasitic capacitance

IGBT Voltage for \( L=80\mu H \) and \( 160\mu H \)

IGBT Current for \( C=150pF \) & \( 300pF \)
Composite vs. Discrete Packaging

Two Package Series Current Switch (TPSCS)
- Added interconnect b/w packages leads to greater voltage overshoots
- Larger area of substrate metallization leads to larger current overshoots

Composite Series Current Switch Package (TPSCS)
- Minimizes contributions of packaging parasitics
- Offers a more robust switching unit
- Greater power density

Advantages of Stacked Wire Bonds

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>N = 1</th>
<th>N = 2</th>
<th>N = 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single (nH)</td>
<td>Stacked (nH)</td>
<td>Single (nH)</td>
</tr>
<tr>
<td>0.1</td>
<td>8.32</td>
<td>6.81</td>
<td>5.90</td>
</tr>
<tr>
<td>100</td>
<td>8.27</td>
<td>6.64</td>
<td>5.66</td>
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<tr>
<td>500</td>
<td>7.97</td>
<td>6.25</td>
<td>5.29</td>
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</table>

- Simulation results obtained using ANSYS Q3D
- Actual performance comparison b/w CSCSP’s with and without stacked wire bonds from IGBT to series diode is currently ongoing

WHAT IS “CSCSP” I'M NOT EVEN SURE PEOPLE WILL KNOW WHERE THE “INDUCTANCE” IS OR EVEN WHAT “OVERSHOOT” MEANS SPECIFIC TO YOUR CIRCUIT.

Hesse Mechatronics BJ939 Heavy

Bonding
CSCSP Thermal Consideration

- Maximum device junction temperature = 150°C
- Power losses as a function of switching loss
  - Calculated @ \( V=3600\, \text{V}, I_c=20\, \text{A} \)
  - Derived from datasheet typical loss data

- COMSOL simulation shows max \( T_j = 146\, ^\circ\text{C} \) using Alumina DBC of original CSCSP design
- Improved cooling method and thermal interface material offer greater \( f_{\text{sw}} \)

CSCSP Packaging Materials

- Substrate: Etched Curamik Alumina DBC 12/25/12 mil, Ni-plated
- Terminals: Copper, cut and drilled
- Power Semiconductor Die:
  - IGBT: ABB 6.5kV, 25A Si
  - Series Diode: CREE 6.5kV, 25A SiC JBS
  - Anti-parallel Diode: 6.5kV, ?A Si
- Flexible Welded Interconnects: Heraeus 15mil Al wire (99.99% pure)
- Housing: Stratasys PolyJet Connex 350 3D Printed VeroWhitePlus RGD836
- Die/Terminal Attachment: ?
- Power Stage Adhesive: 3M ?

SO YOU HAVE SHOWED US WHAT YOU HAVE DONE
YOU’VE TOLD US WHAT YOU HAVE DONE
BUT YOU HAVEN’T TOLD US WHAT CONTRIBUTION
YOU HAVE MADE TO THE INDUSTRY OR TO THE
TECHNOLOGY.
WHY DID THE ATTENDEE SIT THROUGH 30 MINUTES
OF SLIDES? WHAT IS THE “TAKE AWAY”? WOULD
THEY WANT TO SEE THIS TALK AGAIN?
WOULD THEY WANT TO SEE YOU PRESENT AGAIN?
CSCSP Electrical Testing

- High voltage double-pulse test setup
- Successful switching up to 4kV
- No noticeable voltage overshoot during turn-off
- Minimal current overshoot during turn-on

Summary

- A single, composite package approach for series current switch offers greater system robustness due to minimized package parasitics
- Double-pulse testing results display low voltage and current overshoots during switching
- High frequency converters, such as current source based SST, can take advantage of custom Level 1 packaging compared with commercial-off-the-shelf, discrete packages
- Stacked wire bonds have potential to further reduce package parasitics
- Use of 3D printing, along with ability to perform entire packaging process, for rapid-prototyping offers swift realization and testing
- Continuous converter testing using multiple CSCSP’s is now being pursued
Acknowledgements

This work made use of FREEDM Systems Center ERC shared facilities supported by the National Science Foundation (NSF) under award number EEC-08212121, as well as the facilities and equipment located within the PREES Laboratory and its sponsors.

THANK YOU